Chapter 4
Representing Evolution in Science Education: The Challenge of Teaching About Natural Selection

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4.1 Introduction

This chapter will consider the difficulties of effectively teaching about evolution. Firstly, the importance of teaching evolution as part of school science or college courses in biology is established. It will be argued that evolutionary theory cannot be sensibly omitted from any authentic science or biology curriculum. Then difficulties in teaching about the topic will be considered. The argument made here is that there are a number of features of natural selection that make teaching this topic challenging for many teachers but that it is useful to separate these into two major categories. The chapter will discriminate (a) those features which are similar to problems in teaching other 'difficult' science topics (such as force and motion or ionic bonding or photosynthesis) and which relate to intellectual challenges students face in learning about abstract and counterintuitive ideas from (b) those issues particular to topics such as evolution where people in many societal groups actively deny the science and oppose its teaching in schools and colleges. Natural selection is not only a theory that many students find difficult to grasp but also one that many learners have been told is false and perhaps even wicked. All teachers of evolutionary theory will face the first set of challenges, but for those working in particular countries or areas, there will be the additional problem of being asked to teach something that some students find morally objectionable.

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4.2 The Importance of Evolution in Biology

It is generally accepted within the scientific community that evolution is a very important topic in science and that natural selection is a key theory in biology. That position will be strongly adopted here, although it is acknowledged that many people, including a very small proportion of scientists (Hameed 2010), do not accept natural selection describes a genuine process. It is important then to consider the nature of science, to explain how there can be such ‘qualified consensus’.

4.2.1 How Do We Know What Scientists Think?

Before making any statements about the canonical claims of science, it is sensible to offer a caveat. The very nature of science is both dynamic and largely decentralised. The science that is currently considered of merit is – in principle – what the scientific community accepts. Yet there are no regular formal polls where scientists are asked to vote for or against particular ideas being accepted as canonical science. Moreover, although science is democratic in the sense that scientific results and claims are meant to be evaluated in their own terms rather than accepted on the authority of particularly influential scientists, that does not mean that every person who has qualified as a scientist is considered equally qualified to judge any scientific question.

Inevitably modern scientists are specialists, and if one was interested in knowing about the currently valued theories of superconductivity, or the best synthetic route for producing a particular new drug, or the best available understanding of hemispheric lateralisation in the brain, then we would find that (i) most scientists would not be well placed to advise us as the matter was outside their particular areas of specialist expertise, and (ii) even within the relevant subfield, some particular researchers would be considered to have the experience and insight to offer more authoritative views than others. So, to find out whom we should ask, the person outside the field would rely on advice from those within the field suggesting who they thought were the most important experts. There is clearly a sense of bootstrapping here: the people in a field decide who they consider to be in their field (Kuhn 1996) and then who has greater authority within it.

Scientists working within any particular field are usually only able to set up their own labs or be awarded research funds once they are recognised as well prepared to contribute to that field, meaning they have been inducted into the accepted theories, approaches and methodologies in the field (Kuhn 1996). Scientific fields tend to develop through the establishment of specific research programmes that are based upon particular (so-called hard core) commitments established when the programme is initiated (Lakatos 1970), and so scientists working in a field come to take those commitments for granted as long the programme is considered to be making progress.

Science is now so specialised that new researchers are not expected to 'get up to speed' by personally working their way through all the arguments and prior studies that had led the field to its current position – that simply would not be feasible. This is similar to how we cannot expect school students to rediscover all the great ideas of science by open-ended and unguided discovery learning (Driver 1983), as it would take them centuries! This feature of the nature of science does however mean that there tends to be built-in bias in a scientific field that protects key commitments in that field to ensure scientific results fit with, rather than question, those core assumptions. Indeed, one prominent philosopher of science has described the auxiliary theory built up around a field's most precious ideas as acting as a 'protective belt' for those key ideas, offering peripheral 'refutable' (and modifiable) aspects of theory cocooning the hard core ideas (Lakatos 1970).

This means that those working in a scientific field, and so considered experts, tend to necessarily be rather more committed to the key ideas in their field than a naive notion of the critical, open-minded scientist might suggest. The corollary to this is that often – although not always (Kuhn 1996) – the strongest critics of particular scientific ideas tend to be those who are outside the particular field and so have more distance on the scientific questions. External critics may be readily dismissed by those in a field as – by definition – they are not the experts who best know the core topics and the latest research.

We should not be surprised that experts working in evolutionary theory seldom raise questions about the fundamental notion that living things evolve into different species over time. Those scientists who reject evolution (e.g. Morris 1985) tend to have backgrounds in other fields and so lack the expertise and depth of knowledge of evolutionary biologists. The non-scientist has a choice between accepting the minority claims of those who lack expertise in the topic or the opinions of the many experts working in the field who may be so well socialised into the ways of thinking in that field that they find it difficult to recognise potential merits of alternative views (Thagard 1992).

4.2.2 The Status of Scientific Literature

This discussion of the scientific community may seem a diversion, as readers might consider that scientific knowledge is found in publications. Of course individual scientists will be subject to foibles and human limitations, but (it could be argued) scientific knowledge is actually to be found in 'black and white', in the pages of research journals. This is certainly a widely shared notion. However, this is a problematic idea in two senses.

For one thing, there is an argument that publications only contain representations of the knowledge of their authors and that really only people (not journals or books or computers) know things. So, in reading a scientific report, we are not acquiring knowledge that is unambiguously located in the report and can be unproblematically transferred to our brains but rather interpreting *a representation* of someone else's knowledge through our own prior understanding of the topic (Taber 2013a). We are used to thinking about *student* learning in these terms (Taber 2011a), but of course it is a general feature of human learning that applies just as much to teachers and indeed to scientists.

Perhaps an even more serious problem is that the primary scientific literature – generally seen as where scientific knowledge is reported – is vast and often contradictory. Published reports have survived a process of peer review, which means that other scientists in the field considered them to make a genuine contribution to knowledge (which may sometimes just mean they raise an interesting new hypothesis) and so to move forward the understanding of current issues in the field. However, that does not mean that all the claims in published papers are correct: rather simply that they seem to be based on reasonable interpretations of data that had been collected and analysed in sensible ways informed by a theoretical perspective that is considered viable in the field (Taber 2014a). Sometimes there are alternative perspectives related to a phenomenon under active consideration within a field (Lakatos 1970), and so papers from different perspectives might offer contrary accounts of nature, despite each being considered to be making valuable contributions to debate in the field.

Sometimes papers published decades ago are considered classics and still worth reading (Garwin and Lincoln 2003), whilst most others from the same period have long since been seen as surpassed and are now considered largely irrelevant. Usually only those working in the field will know which are which, although citation records (the extent to which papers are cited in other more recent papers) can offer a useful indication. Many newly published papers will make only modest contributions and will be cited very little in future: whilst a few will – in time – come to be seen as seminal. However, even those working in a field cannot always accurately predict which papers will stand the test of time.

The observer outside the field may fare better looking at secondary sources. Reviews of research published in research journals are likely to offer synthetic accounts, albeit sometimes from one of a number of alternative perspectives or research programmes operating in a field. Textbooks at least attempt to offer an overview of current thinking for a non-specialist, but school-level textbooks are inevitably written by non-experts. School textbook authors are often primarily teachers rather than researchers (which potentially helps them build effective pedagogy into their writing as they are more likely to appreciate the appropriate level of treatment), but even if a school textbook was written by an active scientific researcher, it is likely to have a broad scope (e.g. the whole of biology) such that most of the text would concern fields outside the author's own particular expertise. Commonly school texts are only very indirect representations of current scientific thinking.

There are mechanisms by which the scientific community and the general population can be kept informed of major developments in different fields, such as the well-established and prestigious general science journals *Nature* and *Science* and through science journalism, for example, magazines such as *New Scientist* and *Scientific American*. However, it is important for educators to realise that deciding what counts as current scientific consensus or orthodox thinking is not always a clear-cut matter. This is something that should also be borne in mind when curriculum developers and teachers are encouraged to include more on the nature of science in the curriculum. The processes by which science progresses and by which some kind of consensus position emerges are complex and nuanced and may not be readily appreciated by learners unless carefully developed teaching models of the nature of science are adopted (Taber 2008).

It seems then that statements about what science currently tells us, or what scientists currently 'think', need to be measured and qualified as these are not usually straightforward matters. To some extent the classroom teacher will often rely upon some curriculum authority or examining board to set out a representation of scientific ideas as target knowledge for learners of a particular age. Indeed, to some extent, the responsibility for deciding what counts as scientific knowledge rests with curriculum authorities (such as government education ministries or organisations charged with making such decisions in a particular national context). However, when a topic *is* included in the curriculum, the teacher still has a responsibility to offer learners some sense of its status within science, and this may not be a straightforward matter.

4.2.3 Evolution Is Fundamental to Modern Biology

Despite this caveat about the complications that arise when evaluating the current status of scientific knowledge, there are ideas that are generally recognised as being fundamental to the sciences. In chemistry, to offer an example where there is little or no controversy, a core idea is that the structure and behaviour of substances can be explained by theories that assume that matter has a particulate nature at a tiny, submicroscopic scale (Taber 2013b). This idea – let us call it atomic theory – has become so well established, and been found to be so useful, that virtually all of modern chemistry relies upon theoretical explanations built upon this basic notion. In most areas of chemical research, it would be very hard to make any progress without accepting and applying this principle. There may perhaps be some scientists that reject the 'atomic hypothesis', but if so they are surely few in number and have no influence in mainstream chemistry. Within chemistry, the particulate model of matter, the atomic hypothesis, takes on the status of a paradigm of 'normal science' (Kuhn 1996) – a set of ideas so widely accepted that they completely dominate the field compared with alternative views.

In a similar way, a great deal of modern biological thinking assumes evolution: the idea that the types of living things found today, the different species, are modified from ancestors that were quite different and that different species found today are related through descent. That is, individuals from different species share common ancestors, albeit ancestors that lived a very long time ago and are separated from their modern descendants by a very great many intermediate generations. This notion of evolution is generally understood to be possible through a mechanism known as natural selection, first proposed in outline by Charles Darwin and Alfred Russel Wallace (1858), and since developed through a 'modern synthesis' with findings from genetics, into a theory of descent with modification that is very widely accepted by biologists (Mayr 1991). Indeed, like the atomic hypothesis in chemistry, evolution by natural selection has become a core part of the paradigm of modern biology.

Professional biologists would overwhelmingly agree that evolution by natural selection is a central and generally accepted theory in biology. However, there is a small minority of biologists who would disagree and suggest that instead it was simply one model or perspective and that – in their view – it was not sufficiently supported by the available evidence to be accepted. Whilst that is very much a minority view, the analysis above suggests that decisions about which ideas in science are sufficiently well accepted to be considered canonical are complicated by the dynamic nature of science and the complex structure of the scientific community. Unfortunately for the science teacher, there is no website representing 'official science' that is kept updated with a list of the currently approved models, theories, laws, etc., that make up scientific knowledge. As suggested above, science just does not work in that way.

The view taken here, and the position recommended to all science educators, is that evolution by natural selection is the canonical scientific explanation for the origin of different species of living things and a core theoretical principle of modern biology. However, the absence of a formally approved canon of scientific knowledge offers scope for those who have issues with a particular scientific idea (such as evolution) to identify scientists and scientific publications that appear to cast doubt on both the merits and the status of that idea. This is certainly so in the case of evolution. As there are well resourced and highly committed organisations actively advocating against evolutionary ideas, such examples are regularly put into the public domain where it is hoped they will influence people (including students and teachers) to question or reject evolution and its status as widely accepted scientific knowledge.

Although evolution by natural selection may not seem to the layperson to be obviously relevant to many issues in biology, it has become so central to key explanatory schemes of how living things come to be the way they are that – like the atomic hypothesis in chemistry – it has become an integral part of the nature of biology as understood today. Perhaps to the school or college student, evolution is seen as just one topic among many and has little to do with understanding other topics such as, say, digestion. Yet to the modern biologist who has been trained to adopt an evolutionary mind-set, evolution has *everything* to do with digestion: the structure of the alimentary canal, the presence of specific digestive enzymes, the nature of the blood supply, the incidence of appendicitis, and so forth are all understood in terms of the evolutionary journey through which an organism's anatomy, physiology, and biochemistry came to have the form they have today.

Indeed, one key evolutionary thinker, Theodosius Dobzhansky (1973), went so far as to publish an article aimed at biology teachers entitled 'nothing in biology makes sense except in the light of evolution'. One could seek to quibble with the absolute inclusiveness of the claim (really, nothing at all?), but most biologists would feel that, if anything, the argument has become stronger in the years since Dobzhansky's article was first published.

Like the atomic theory in chemistry, evolution has acted as a major integrative theory in biology, which has allowed results from across a whole science to be understood within a common theoretical framework. Indeed there is even an argument that the theory of natural selection helped facilitate the transition of biology from being nature study ('natural history') to a mature science. Darwin set out on the Beagle as an amateur naturalist, but through his life's work, he did more than anyone to establish biology as a suitable discipline for a professional scientist.

4.3 The Importance of Evolution in Science Education

Given the importance of evolution to biology, there is a very strong case for considering it to form the basis of an essential topic in the science curriculum. This argument can be made at two levels. For one thing, evolution can be seen as an important topic in its own right, simply in terms of reflecting the pattern of scientific activity in the discipline. Evolutionary studies are a substantive part of biological research and provide a major area of activity for those who might decide to enter into professional work in the life sciences. Evolutionary theory offers accounts of the diversity of the biota, which might be considered an important question for biologists to be concerned with. So, as an important topic, evolution should be included in the school/college biology/science curriculum alongside other important topics. In particular, a school science curriculum that omitted evolution is ignoring one of the most important topics in the subject.

However, if we accept that very little in modern 'biology makes sense except in the light of evolution', then we can go beyond this argument to suggest that evolution has a stronger claim on its place in the science curriculum than many other biological topics. Ecological relationships cannot be understood, at least in the way they are understood in modern biology, except in terms of evolution; the geographical distribution of different species cannot be understood, at least in the way it is understood in modern biology, except in terms of evolution; and so forth. From this perspective we might argue that (i) if there is pressure on the curriculum, and only a limited number of biological topics can be included, then evolution should have the highest priority, as it is a more important topic than other biological topics and (ii) if evolution is seen as a key underpinning of a modern understanding of biology, and a core theoretical perspective for understanding other topics, then evolution should have a central role in the biology curriculum, and should be used as an organising theme, introduced as an early topic that is then drawn upon (and reinforced and developed) in learning other topics.

This position is consistent with the proclamations of many organisations concerned with science education and the public understanding of science. For example, the US National Science Teachers Association (NSTA) 'strongly supports the position that evolution is a major unifying concept in science and should be included in the [school] science education frameworks and curricula. Furthermore, if evolution is not taught, students will not achieve the level of scientific literacy they need' (National Science Teachers Association 2013).

4.4 Impediments to Learning About Evolution

There is a large body of research into the nature of learning in science and into the ideas about scientific topics that have been elicited from learners before and after teaching (Duit 2009; Taber 2009). Much of this work is based on a constructivist perspective that sees learning as an active process of meaning-making, which is channelled by the existing state of a learner's knowledge and understanding (Driver et al. 1994; Fensham et al. 1994; Mintzes et al. 1998). As with many other topics, research suggests that learners tend to develop their own notions around evolution which often do not fit the scientific accounts being taught in the curriculum (Wood-Robinson 1994).

4.4.1 The Challenging Nature of Natural Selection as Target Learning

There are a number of features of evolution as a topic that make it challenging for most students. For one thing, natural selection is a complex theory. Now the target knowledge presented in a school curriculum is not usually at the level of the current frontiers of scientific knowledge but rather based on simplifications suitable for the age and ability of the learners – with some of the less essential detail and confusing complications omitted. Such simplified versions of scientific ideas do however have to be what Jerome Bruner (1960) referred to as 'intellectually honest' simplifications that retain the essence of the more sophisticated scientific models. An optimal level of simplification offers a version of the scientific account that students can access and make sense of, yet which is still good enough to provide a sound basis for later progression through more advanced learning (Taber 2000). The challenge of developing such simplifications is greater in some topics than others.

Evolution by natural selection is problematic because although it is intellectually satisfying for the learner who has mastered it, and indeed often appears a 'simple' idea to experienced biologists, it only fully makes sense once a range of different ideas are coordinated together into a complex scheme. These ideas relate to how genes inform the development of individual characteristics, how genes are passed through hereditary, how occasional 'copying errors' occur leading to mutations, variations of characteristics within species, the failure of some (most in many species) offspring to themselves reproduce, the relationship between surviving to maturity and reproductive success on the fit between individual characteristics and environment, the possibility of geographical separation of distinct breeding populations within the same species, and so on (Taber 2009).

A second problem with natural selection is that it is counterintuitive for many learners because we lack direct experience of key features (the timescales over which natural selection occurs are so far from human experience), and our experience of the world generally reflects discrete and quite distinct species (Ruse 1987/1993). The former point is important because it is difficult to appreciate the sheer number of generations separating, say, the last common ancestors of humans and chimpanzees and their modern descendants.

Yet this timescale is important given that natural selection works with myriad chance events. Each fertilisation event reflects a successful union between particular packets of genes that could so easily have been different (given the number of sperm likely to be potentially able to join with a particular egg, if we consider mammalian fertilisation as an example). Within any particular environment, individuals born with the best *potential* characteristics for reproductive success are only *slightly* more likely to *actually have* reproductive success than their peers – as they still risk predation, starvation, drowning, poisoning, etc., even if at a slightly reduced level of risk compared to those peers. As the evolutionary theorist Stephen Jay Gould (1991) pointed out, so much in evolution is contingent: there is a limit to the extent your genes will prevent you from being in the wrong place when a hungry predator, a landslide, a volcanic eruption, or a tsunami, arrives.

The second point is perhaps more of an impediment. The idea that there are certain discrete ‘natural kinds’ of living things seems to be part of folk biology in diverse cultures (Medin and Scott 1999) and an idea spontaneously developed from a very young age (Keil 1992) – suggesting that there may even be a genetic predisposition to forming a cognitive bias towards recognising natural kinds in the world. So, ironically, evolution may have predisposed us to see the world in terms of a discontinuity of living things that is an impediment to appreciating evolution.

Darwin and Wallace (1858) recognised how the diversity of life on earth could be related through descent from common ancestral forms, and there is now a vast evidence base to support this view from comparative anatomy, palaeontology, molecular biology, etc. However, their insight was based on years of close engagement with samples, from myriad species in diverse habitats, and consideration of fossil forms. Darwin famously represented the process as a great bush of life, yet most people only experience a small part of what is in effect a single transverse section of that bush (see Fig. 4.1).

From the scientific perspective – the development of the ‘bush’ of life as shown in Fig. 4.1 – the species we see today are temporary islands of stability within an inherently dynamic picture of life that (when considered at the geological scale) is always in flux. Yet the environment we experience presents us only with the apparent discontinuity of the biota at one moment in earth’s history, not the continuity highlighted by the scientific perspective. This is perhaps accentuated if, as has been suggested, evolutionary change does not tend to be uniform, but instead proceeds through a series of punctuated equilibria (Gould and Eldredge 1977, 1993/2000)

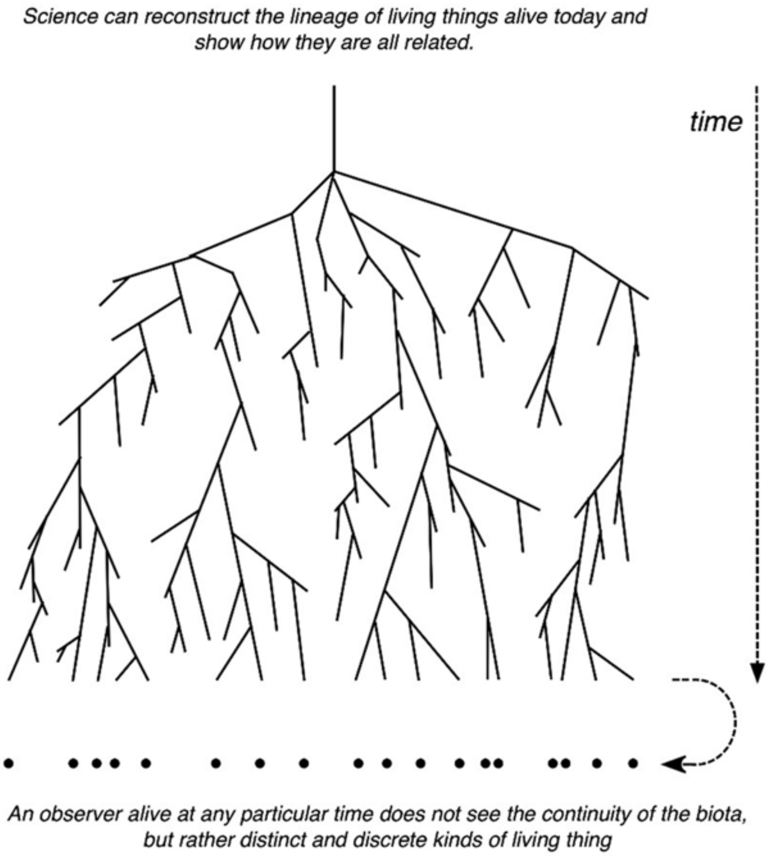

Fig. 4.1 The scientific perspective on the evolution of living things considers 'deep time', whereas the everyday experience of learners is limited to a 'snapshot' of the species alive at one geological moment

such that significant changes tend to occur only during a small proportion of the evolutionary history of any species, as the fossil record will predominatnly reflect the periods of equilibrium.

An additional common problem for teaching concerns the status of natural selection as a scientific idea. Evolution by natural selection is *a theory*. This means that it is not something scientists are setting out as a proven fact, as an absolutely certain account, but rather as an explanatory narrative that is conjectural and open to revision. However, that should not be understood to mean that natural selection is a low-status idea within science. To scientists, theories are well-developed systems of concepts that are strongly supported by evidence and which have been found to have considerable explanatory and predictive power. Although scientific knowledge is *in principle* provisional, some theories (such as natural selection) are so well supported that they come close to being considered as if factual for most purposes. Yet, technically, they have not been – and nor can they ever be – 'proved'.

A modern understanding of science does not admit the possibility of absolute proof of general ideas (Popper 1934/1959). All scientific generalities are – strictly – logically underdetermined by available evidence and inevitably reliant upon fallible interpretation (Kuhn 1996; Lakatos 1970). That is not considered a failing of science but rather a reflection on the limits of human knowledge. All scientific knowledge is subject to these constraints: science produces models and theories and then selects and develops those found to be most useful in the light of further testing.

This principled limit to the status of scienific knowledge, which is now well accepted among philosophers of science, creates a major challenge for science teachers when they are asked to help learners understand the nature of science (Hodson 2009). This is especially so for learners who are still developing the intellectual ability to effectively cope with complex and uncertain information – and this is likely to include most school pupils and many college level students (Perry 1970). The teacher has to help learners appreciate that scientific knowledge is always, technically at least, provisional and open to being revised, whilst claiming that science has reliable apparatus for developing robust and trustworthy accounts of the world.

What *is* known is that commonly learners have developed much less sophisticated understandings (Driver et al. 1996), such that they do not appreciate the nature, and in particular the status, of scientific theories. So, secondary-age learners, for example, may simply consider a theory to be an idea a scientist had – little more than a hunch or a guess (Taber 2006) – rather than the outcome of extensive development of a formal perspective that is consistent with evidence and coherent with other key ideas in science. Lacking a sophisticated understanding of the nature of science often means that students do not appreciate how (i) acknowledging that theories are not 'proven' is *not* the same as (ii) considering them as just hunches awaiting testing (Taber et al. 2015).

To return to a comparison used earlier, the particulate nature of matter that is so central to modern chemistry is, like natural selection, technically only theoretical knowledge. Yet, like the evolutionary modern synthesis, it provides a basic framework of understanding relied upon by effectively all scientists working within the discipline. Its theoretical status does not undermine its central importance in science. By its nature, science develops abstract generalised knowledge that is inherently theoretical. Without theory, science is reduced to natural history collecting and loses its explanatory power. Not all scientific theories are well developed and strongly supported by evidence: but just like particle theory, evolution by natural selection is considered 'reliable' knowledge (Ziman 1978/1991).

4.4.2 Teaching Evolution and Conceptual Change

This analysis suggests that teaching about natural selection is always likely to be challenging for teachers, as it is both a complex theory and an area where students' existing learning is often likely to be suboptimal for constructing good understanding of the scientific ideas. Each of these issues is very common in science education.

When teaching complex ideas, teachers have to scaffold learning in ways that help learners build up an overview of a topic with support until they are in a position to see how the components of the theory fit together in a coherent and logical way. Teaching from a constructivist perspective is a challenge for teachers – who have to both work out how to teach from the students' starting points and offer optimally guided instruction (Taber 2011a) that structures content into manageable 'learning quanta' (Taber 2005) and supports personal construction of knowledge with suitable 'scaffolding' (Wood 1988).

Teaching science therefore involves the teacher in building metaphorical conceptual bridges or ladders between students' current knowledge and the scientific concepts prescribed in the curriculum (Leach and Scott 2002). Teachers have to understand the learner's starting point and work out how to proceed stepwise using various pedagogical tools to help the learner make sense of scientific ideas. Those tools include models, demonstrations, analogies, metaphors, examples, thought experiments, etc. There is much that can go wrong in this process, as evidenced by the extensive literature describing students' failures to learn – or at least failing to learn what was intended rather than developing their own alternative conceptions of the subject matter. A range of types of learning impediments may occur (Taber 2005): for example, students may lack expected prior knowledge, or may fail to see how it relates to new instruction; students may misinterpret teaching through existing concepts that are inconsistent with scientific knowledge; or they may make creative, but unhelpful, connections between instruction and unrelated prior knowledge.

A particular problem with the usual pedagogic tactics teachers commonly adopt is that when they are used to make evolution accessible, they may encourage misconceptions. A lot of the language used tends to personify nature and/or imply teleology – that evolution is seeking to do something specific as if there is foresight at work or specific target states built into the process (Ruse 1986/1993; Zohar and Ginossar 1998). Darwin himself used personification as a device in explaining natural selection (Beer 1986).

There is also a tendency for students who have no principled objection to evolution to find Lamarckian models of evolution (where individual organisms change during their lifetime in response to environmental conditions and then pass on these acquired characteristics to their offspring) more feasible. This is despite Lamarck's ideas being considered to have been 'easily and repeatedly refused by all writers on the subject of varieties and species' and 'finally settled' by Wallace's time (Wallace 1858/2003). The author of this chapter has interviewed students who have explained that inheritance of acquired characteristics is what they have been taught in school science, although the author suspects this is rather how they personally made sense of what they were taught (Taber 2014b).

There are many other topics where learners' everyday experience fails to provide sufficient background as the foundation for building up scientific knowledge (so teachers need to provide demonstrations, analogies, models, etc.) or where scientific ideas seem to be counterintuitive (the relationship between force and motion, for example, (Gilbert and Zylbersztajn 1985)) or to be inconsistent with folk-theories (that exercise can produce energy, for example, (Solomon 1992)), and approaches have to be developed to help learners to appreciate the scientific models. That this is seldom a simple matter, and that the best strategy may vary across science topics, is reflected in the extensive literature discussing how to best teach for conceptual change (Vosniadou 2008). Natural selection is therefore going to be inherently a difficult topic to teach effectively, without any consideration of potential clashes due to learners' religious commitments.

4.5 Worldview Commitments and Learning About Evolution

Yet, in addition to the inherent problems with natural selection as a complex and counterintuitive idea, those charged with teaching evolution often have the additional complication that learners in some classes will reject evolution on principle (Hokayem and BouJaoude 2008) because they consider the notion is contrary to core commitments that make up part of their worldview (see the discussion of metaphysical commitments and worldview in Chap. 3).

Some communities reject evolution because of commitments to alternative general ideas about (a) the origins of the biota and/or (b) the potential consequences of evolutionary ideas for the nature of human beings. Although it is difficult to generalise, because different communities that object to evolutionary ideas hold different beliefs, problems commonly arise due to commitments to accounts in religious Scriptures as being technically accurate (rather than offering theological or metaphorical truths – again see Chap. 3). Particular problems among some Christian communities may relate to beliefs that:

(i) God created the world through a number of discrete acts of creation, bringing into being different classes of animals and plants through their own special creation event.
(ii) The creation occurred sometime in the last 10,000 years.
(iii) Human beings are more than just a particular type of animal, having a different relationship to God than other living things.
(iv) Death was not initially inevitable for humans and (sic, other) animals – there was no death until sin entered the world.
(v) God renewed his covenant with humanity following a worldwide flood, from which were saved specimens of the types of creature he had created previously.
(vi) The cosmos beyond the earth was created as a perfect realm which is unchanging.

4.5.1 The Creation of Living Things

Scriptural accounts of the creation of the world in Genesis (in the Jewish Torah and Christian Old Testament) refer to God creating different types of living things as part of a staged 6-day programme of creation. There are very different traditions in Christianity about how such accounts are to be read, and in many Christian traditions they are understood as poetic or metaphorical accounts conveying deep theological truth. However, during the twentieth century, a number of Christian denominations in the US popularised the notion that these accounts should be taken as true technical accounts of the creation of the world (McCalla 2006).

From this perspective the main types of living things alive today are descended from the different discrete types of living thing originally created by God. The evolutionary notion that all living things on earth may have developed from the same, much simpler, ancestor organism is completely inconsistent with the beliefs of those holding a religious commitment to Genesis as a literal account.

Usually there is no objection to the idea that within the main groups of living things created by God, different descendent populations might diverge to give different variations (sometimes referred to as microevolution) but always within the bounds of the general type of organism God originally created. The notion that animals may have descended from fundamentally different types (known as macroevolution) is completely excluded by this perspective.

4.5.2 The Dateline

Jesus, the founder of Christianity, is a historical figure, so there is little dispute over when he lived on earth and carried out his ministry (about 2000 years ago). The Christian Scripture offers his genealogy in the form of an unbroken male line back to Adam, the first man. Based on this (and various clues in the Old Testament), it is possible to produce a timescale for the creation of the world and Adam. One scholarly calculation that was influential in the eighteenth century suggested that the creation occurred about 4000 years before Jesus's birth (starting on October 23, 4004 BC), and whilst this rather precise date has since fallen into dispute, many of those who today reject evolution because of its inconsistency with Christian Scriptures consider that the earth is no more than about 10,000 years old.

Clearly a figure of 10,000 years is completely contrary to the scientific view that the earth is something like 4,500,000,000 years old (and the Universe much older). The much shorter timescale is inconsistent with the time needed for evolution to occur through natural selection.

4.5.3 The Special Relationship

A particular problem that some groups find with evolution is the idea that humans evolved over millions of years from earlier hominids that in turn had themselves evolved from earlier non-hominid species. Evolutionary theory suggests, that in biological terms at least, there is nothing special about humans marking us off as separate from the rest of the biota. Scientifically, we are primates, and mammals, and indeed animals, and only as special as any other particular species.

This is completely contrary to the notion that human beings were marked out as a special creation by God. Scriptural accounts are read to imply that humans were always intended to have a special relationship with God and seen as distinct from the rest of creation. In some religious traditions, humans have immortal souls that survive death whereas other animals do not. In some traditions, the rest of the biota is seen as provided by God for mankind's use – a perspective that may not always encourage strong ecological thinking (although in some religious traditions, people are also considered to be in stewardship of nature and responsible for it to God).

Perhaps a major area of contention is the issue of the boundary between humans and non-humans. In some religious traditions, this is unproblematic, because it is taught that God created man separately from other kinds. However, the scientific account offered through evolution by natural selection suggests that if we were able to move back generation by generation, there would be no sudden discontinuity between humans and their prehuman ancestors, but rather there has been a slow process through which creatures developed that we now consider human. On the evolutionary model, there would be many generations of ancestors where there would be no clear basis for considering them definitely human or definitely prehuman. The scientific account presents challenges for those who see humans as in a special relationship with God (Rachels 1990): for example, does a severely mentally damaged newborn child have an immortal soul, whilst a modern chimpanzee does not?

Darwin was certainly aware of the potential difficulties of his evolutionary ideas conflicting with religious views on the special status and nature of humans. Darwin only made a brief allusion to the question of human origins in his 'Origin of Species' (1859/1968), leaving the topic for a later book (Darwin 1871/2006) only published once his evolutionary ideas had been widely discussed and come to be generally accepted in many quarters.

4.5.4 The Fall

Another tenet of some 'fundamentalist' traditions in Christianity is 'the Fall'. According to Scripture, Adam and Eve disobeyed God's direct command in eating from the tree of knowledge. This event is considered as man inviting sin into a world that God had made perfect (Williams 2001). In this tradition, there was no death prior to the Fall (Messer 2009; Moreland and Reynolds 1999), and all of the creatures of the earth had coexisted peacefully (and so were all herbivores); but afterwards prey-predator relationships developed. The scientific interpretation of the fossil record is inconsistent with the idea that at one time all animals were plant eaters. The Fall is often considered very important in Christian thinking as it is related to the idea of salvation in Jesus Christ and the possibility of eternal life with God after death.

4.5.5 The Flood

The Genesis account does not only record the creation but also a later cataclysmic event where God sent a worldwide flood to punish humanity for its evil ways, only saving one family (Noah and his three sons, and their wives, who were forewarned to build a great ark) who would be the ancestors of all humans in the world after the deluge. God also had Noah and his family save stock of all the animals he had created to repopulate the animal world as well. Many of those who adopt the scriptural account as an accurate technical account consider this event as very significant in human history and see the act of saving representatives of the different animals God had created in keeping with the idea of them having been created as distinct types unchanged from the creation, through the deluge, to the present day (McCalla 2006).

The scientific account of earth's geology suggests there have been enormous changes in the face of the earth since its formation due to seismic activity and plate tectonics, changes in the atmospheric composition, etc., whereas many of those who reject evolution feel that the earth is basically unchanged since its creation, apart from the powerful effects of the great flood.

4.5.6 The Heavens

Many who take scriptural texts as offering a literal account of the creation and history of the world find Scripture to disconfirm scientific ideas about cosmology. An obvious point of contention is scientific accounts of the earth as orbiting a second-generation sun, because the earth is composed mainly of elements that were created in the nuclear furnaces of earlier suns and which – according to scientists – were not present in the Universe until they were formed in stars. The scriptural account of creation is often read as allowing 6 days for the whole creation process and does not allow for billions of years between the formation of first-generation stars and the formation of the earth.

Moreover, scriptural verses can be read to imply that heavenly bodies are unchanging, so the notion of stars themselves passing through a kind of life-cycle and then being destroyed in supernovae is seen by some as completely contrary to Scripture (Morris 2000).

4.6 Young-Earth Creationism

These scriptural perspectives are often associated together in the notion of young-earth creationism (YEC), a worldview that excludes the possibility of cosmic evolution, geological timescales, or evolution of species through natural selection. From the scientific perspective, such a position is untenable given the vast evidence base from diverse fields such as astronomy, geology, palaeontology, comparative anatomy and molecular biology.

However, of course, scholarship into the nature of science reminds us that evidence never unproblematically leads to particular definite conclusions. Rather, any empirical evidence is always interpreted within some theoretical framework or other. This is one reason why few scientific experiments or observations can be seen as completely refuting a hypothesis (Lakatos 1970): conclusions always depend upon evidence, *plus* its interpretation. If we reject some aspect of the theoretical framework, we can reinterpret the evidence. So, when Galileo (Galilei 1610/1989, p. 35) suggested that Jupiter had its own satellites ('four planets hitherto never seen'), based on 'observations recently made, with the benefit of a new spyglass', some of those who were not open to such a possibility (because it seemed to be contrary to scriptural teaching) rejected his evidence on the basis that they did not accept the validity of his instrumentation – the telescope.

Similarly today, various arguments are used to fit scientific evidence into different interpretative frameworks by those who reject the scientific interpretations. There are museums in the USA where dinosaurs are displayed as being contemporaneous with humans rather than part of an earlier evolutionary epoch. To many working in science education that seems ridiculous, but surveys suggest that *most people* in the USA accept this idea (McCalla 2006). Indeed some even suggest that such creatures are only not around today because – for whatever reason – Noah did not take them in his ark.

Similarity of anatomy and biochemistry across species can be understood by those adopting YEC as evidence for God having used optimal designs that therefore were very similar across different parts of His creation. Methods that date rocks and suggest some rocks are millions or billions of years old are based on flawed assumptions, YEC adherents would claim: we cannot know that radioactive decay rates have been constant during earth's history, as we did not have the technology to test this during most of the earth's 10,000 years.

Ultimately, regardless of how superior the scientific account may seem to science teachers in terms of fitting a diverse and extensive evidence base, such arguments are of limited value in persuading those who find evolution to rely upon or suggest ideas that are directly contrary to matters they take as central to their religious convictions. If you 'know' that the earth is young, and evolution does not occur, because this is seen as central to your religious faith, then no amount of argument from scientific evidence is relevant (Long 2011). In some parts of the world, children are being told by their parents and Church elders that evolution is false and often that it is an evil idea that leads otherwise decent people on the road to eternal damnation (see below).

Leaders of YEC movements are aware that science has a vast evidence base it uses to persuade people of the worth of evolutionary theory, and so they invest time and scholarship into addressing scientific arguments, looking for flaws, identifying minority dissenting voices from within the scientific community, and offering alternative interpretations of scientific evidence that can appear convincing from within the YEC worldview. The YEC movement does not need to provide young people with convincing creationist accounts of all possible scientific evidence but just enough examples of how the evidence can make sense from a YEC perspective so that when they meet evolutionary evidence in school or college, they are convinced that there must be a perfectly good explanation for that data that fits with their own convictions.

4.7 Moral Objections to Evolution

As well as arguments for rejecting evolution based on inconsistencies between religious commitments and the details of the scientific account, there is also what might be considered a 'secondary' line of argument that evolution and championing of evolution are not simply incorrect according to religious teaching but actually represent something that is (from this perspective) inherently bad or evil.

From a scientific perspective, a theory can be more or less supported by evidence but cannot be morally good or bad. However, people may draw implications for behaviour based on scientific theories, and so theories may be seen to be associated with ideological positions that others judge as morally desirable or undesirable. Certainly some commentators see evolutionary ideas as dangerous or morally wrong, and this seems to be based upon at least three distinct issues:

(i) Evolutionary ideas lead to people questioning the authority of Scripture and so doubting articles of their faith.
(ii) Evolution is part of an inherently atheistic and materialist worldview that denies the existence of God Himself.
(iii) Evolution supports values and ideologies at odds with the moral teaching of religion.

Issue (i) is clear from the discussion of possible interpretations of religious Scripture above. Issue (ii) is less clear-cut. Evolution itself is not inherently atheistic and indeed, even Darwin – who found much evidence to bring into doubt the Christian account of a personal, loving God – did not see natural selection as an absolute reason for excluding the existence of a creator God (Mandelbaum 1958).

This issue is complicated by the stance taken by a minority of scientists who are atheist materialists, who consider that their perspective should be the proper basis for science itself and who seem happy to encourage debate on the basis of setting acceptance of scientific accounts of origins against what they see as irrational and primitive supernatural alternatives. Although this group is not representative of the scientific community (see Chap. 3), they do have a high public profile in some countries and so may often *be thought to* represent the scientific view.

4.7.1 Ideological Positions Associated with Evolutionary Ideas

Issue (iii) concerns the *implications* that some might consider follow from accepting natural selection. It has been suggested that opposition to evolution within Muslim communities is generally of this kind as the Qur'an is not usually considered to specifically exclude evolution (Hameed 2010).

From a scientific perspective, the theory of evolution (in common with any other scientific theory) does not tell people how to behave, but such theories can inform ideologies and lead to questioning of cultural traditions. So, for example, if all living creatures are related by descent, and species are not absolute, the tradition of not eating other human beings (something taboo in most human cultures), but eating other mammals, could be questioned.

Evolution has certainly been *associated* in the past with eugenics (Bowler 1983/1989), and so with suggesting it might be acceptable to not allow those with inheritable diseases or of severely low intelligence levels to reproduce. As always, science cannot offer a view of what is right or wrong but only help inform us of what is technically possible and what the likely consequences of different actions might be.

Yet some opponents of evolution have stretched the argument to make claims that belief in evolution is responsible for various things seen (from their perspective) as undesirable, including Nazism, communism, fascism, romanticism, homosexuality, promiscuity, imperialism, teenage pregnancy, divorce, public unrest and so forth (Berry 2009; Hameed 2010; Yahya 2008). One popular writer and speaker against evolution went so far as to describe evolution as 'the philosophy [sic] underlying all the evils of the world' (Morris 2000, p. 18).

Whilst this is nonsensical from the scientific perspective, there *are* some people who will use arguments about evolution to justify behaviours or opinions others find undesirable. Many learners in science classes, especially at school level, will not be well placed to make distinctions between the science and the ideology, and if they come from communities where they are warned that evolution is an immoral and dangerous 'philosophy', then they may understandably tend to be very wary of classroom teaching about evolution.

4.8 Creation Science

Some of those who reject evolution and oppose the teaching of evolution attempt to locate their arguments within a scientific perspective or at least to claim that their argument is based on scientific evidence (McCalla 2006). In many parts of the USA, there has been a campaign to teach about creationist views in schools as a counter to the teaching of evolution. The US constitution does not allow the teaching of religion in state schools, but the argument has been made that (a) evolution is only a theory and not known definitively to be true and (b) that there are alternative interpretations of the scientific evidence that should also be taught. Point (a) is correct but would apply to any other scientific theory: plate tectonics, the role of enzymes in digestion, flux cutting as a mechanism in electromagentism, the particulate nature of matter, etc. There have not been major campaigns to have alternatives to these other ideas taught on the basis that they are only theories and not definitive knowledge.

Creationists will tend to marshal evidence to support their alternative views, although this sometimes involves scant regard for well-accepted scientific principles: adherents of so-called creation science have been said to ‘play fast and loose with the facts of geology and biology’ (Mandelbaum 1958, p. 381). So, the theory of punctuated equilibria, that suggests evolutionary change tends to be uneven, is presented by creationists as scientists acknowledging that the fossil record does not provide evidence of modification *and therefore* provides no support for natural selection (Morris 1985).

As an example, one book written by an author who taught science at a British university (Pimenta 1984, p. 29) argues that because all matter was created from hydrogen (*all* atoms of which, the reader is told, contain neutrons), it is reasonable to suppose that all bodies in the Universe contain hydrogen deep within them (which does not follow), which is liable to be sufficiently heated by radioactivity to give rise to sudden events ‘equivalent to millions of subterranean hydrogen bombs’ (which certainly would not follow). This (non-feasible) violent mechanism is mooted to explain the current appearance of the earth with its apparent geological history, despite a recent creation. According to Pimenta, radioactive methods that date rocks to great age ‘cannot be valid’ *because* time only began about 6000 years ago. He suggests that the rate of decay of elements has been shown to have changed significantly in recent centuries and that when it is used to persuade people of evolution, it amounts to ‘a satanic ploy’ (p. 238).

These efforts to present alternative interpretations of scientific evidence, and sometimes scenarios completely disregarding scientific evidence, may be well resourced – explaining the museums in the USA that present geological and paleontological material arranged in accordance with YCE interpretations. In general, however, these approaches have made few official inroads into state education – although that does not mean that classroom presentations always cover evolution according to the curriculum (Long 2011). Elsewhere, copies of beautifully illustrated hardback books (volumes of an ‘Atlas of Creation’) reflecting an antievolutionist stance have been distributed to thousands of schools in some countries, from an Islamic organisation in Turkey (Hameed 2008). This material claims that Darwin's theory was derived from his imagination – which in a sense is inevitably true of course (Taber 2011b) – and had no basis in 'scientific evidence or findings'; rather because science was 'fairly primitive' in Darwin's time, people did not recognise 'the full extent of the ridiculous and unrealistic nature of his assertions' (Yahya 2008).

4.8.1 Intelligent Design

In recent years a new strand of thinking has developed, known as intelligent design or ID. The ID movement is not formally linked to any religious organisation and accepts the geological evidence for the age of the earth and much of the evidence for *some* aspects of evolution. However, ID adherents argue that there are aspects of the structure and organisation of living things that demonstrate a kind of irreducible complexity that is inconsistent with being formed through random events in natural selection (Behe 1996, 2007). The scientific account of natural selection argues that complex structures such as the mammalian eye or a wing capable of supporting flight developed in small steps – a proto-eye simply offering a gross indication of light intensity and direction; the precursor to the wing just supported gliding between branches, and not actual flight, etc. (Dawkins 1988).

However, ID supporters argue that there are some complex structures at cellular level that only offer any advantage to the organism once they are fully formed (Behe 1996). The bacterial flagellum was a choice example: a structure composed of specific subsystems which all had to be present and properly integrated to function but which individually offered no obvious value to the organism. The ID argument runs that given such complexity could not have been provided by natural selection (which would not favour the commitment of resources to building structures that only have a viable use many generations later), then such structures demonstrate that organisms have at some level been designed by an intelligence. According to ID, evolution occurs but cannot be the whole story: rather evolution is helped and steered by some guiding intelligence. The official ID stance does not identify such intelligence with a God (rather than perhaps a very advanced alien genetic engineer), but that is the association that is available to those who wish to adopt it.

Because ID accepts most of the scientific account, and looks to adopt scientific evidence, its proponents have claimed it should be seen as an alternative scientific account and so considered in courses teaching evolutionary theory. However there are a number of objections to ID. One is that it adopts non-scientific (non-testable) hypotheses (Alexander 2009). That is, science should look for naturalistic explanations and not invoke God or other teleological arguments to cover gaps in scientific knowledge. This is not an argument that necessarily excludes God but assumes that scientific explanations must be based on evidenced mechanisms rather than conceding that some natural phenomena may not have natural explanations. This is a position that most religious scientists would adopt (Alexander 2009) as part of ‘methodological naturalism’, the idea that within the work of science, only natural mechanisms and explanations are adopted (see Chap. 3).

ID has also been seen by many working in science education as an attempt to offer a version of creationism that might be admitted into the science curriculum. However, ID has been widely rejected by the scientific community, and many organisations concerned with science and science education have taken public positions opposing the teaching of ID in science classrooms. The Association for Science Education in the UK issued a statement on ID to the effect that:

> it is clear to us that Intelligent Design has no grounds for sharing a platform as a scientific ‘theory’. It has no underpinning scientific principles or explanations to support it. Furthermore it is not accepted as a competing scientific theory by the international science community nor is it part of the science curriculum … Intelligent Design has no place in the science education of young people in school.
>
> (Association for Science Education 2007)

4.8.2 Responding to Creationism in the Classroom

It has been recognised that science teachers working with students who reject evolution on non-scientific grounds face a particular challenge, as no amount of argument or appeal to evidence is likely to be effective when the whole idea of evolution seems contrary to deeply held beliefs. Advice to engage with students’ viewpoints (Reiss 2008) has alarmed some scientists (see Chap. 3) and may make some science teachers uneasy due to their limited preparation for dealing with religious questions.

A useful perspective may be to keep in mind that science is not meant to be about belief and the teacher’s job is not to persuade students to believe in evolution by natural selection or indeed any other theory (Taber, in press). The teacher’s job is to help students understand (i) the scientific model and (ii) the evidential basis for that model. Teachers are likely to make more headway in helping learners from creationist communities understand natural selection if it is presented as a theory to be understood and critiqued and not as a true account they are being asked to believe.

Such a strategy will clearly be more viable in classrooms where science is generally taught from a perspective informed by a modern view of the nature of science, so scientific knowledge on all topics is presented as reliable – but also conjectural, theoretical and inherently open to review. Students in classes that regularly learn about historical scientific models which were once widely accepted, but become replaced as new evidence became available, will be used to critiquing scientific ideas and will appreciate that this is important for scientific progress. In such a context teachers can invite questions and objections to natural selection (as they would with other topics) but ensure that these are all dealt with in terms of the scientific evidence. The aim must not be to demonstrate that evolution by natural selection is ‘true’ but rather to show why it is currently considered the best available scientific account.

4.9 Conclusion

This chapter has considered the challenges involved in teaching about evolution. Natural selection is a difficult and counterintuitive idea for many learners, and teaching about the theory is commonly misunderstood by students. There is much research into learners' ideas in science and how to address them that can offer teachers some guidance on how to develop presentations of evolution that will allow learners to construct their own understandings in keeping with scientific ideas.

However, this is complicated in many national contexts where learners may understand evolution to be contrary to religious teaching. Sometimes learners may have even been told that evolutionary theory itself is in some sense an evil idea that corrupts society and undermines faith. The science education community in many parts of the world has held firm to the idea that evolution should be taught and that it should not share the science classroom with presentations of creation science or alternatives such as ID. This seems a sensible policy: science teachers should teach the currently accepted scientific theories, emphasising both that they are theory but also that they are strongly supported by empirical evidence. However, it is much less clear how to effectively respond to the reactions of those students who themselves bring creationist beliefs into the classroom, and to do so in ways that both do justice to science and show appropriate respect for the values and views of the learners. Arguably, science teaching that is informed by a perspective from the history and philosophy of science, and where learners appreciate the nature and status of scientific models and theories, is more likely to support students in learning about natural selection, without them feeling they are being asked to accept ideas contrary to their own convictions.

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